TABLE 1.—*Days and hours with fog in Northwest for November 1933*

Station	Light fog		Moderate fog		Dense fog	
	Days	Hours	Days	Hours	Days	Hours
Portland-Medford Airway:						
Portland, Oreg	23	106	18	103	16	88
Salem, Oreg	25	104	22	76	19	133
Eugene, Oreg	25	111	20	65	22	217
Roseburg, Oreg	26	95	17	54	23	169
Wolf Creek, Oreg	0	0	6	6	25	165
Sexton Summit, Oreg. (elevation 3,855 feet)	2	3	1	2	7	81
Medford, Oreg	16	51	11	17	15	109
Portland-Seattle Airway:						
Castle Rock, Wash	26	283	22	62	19	111
Chehalis, Wash	28	178	21	83	15	88
Tacoma, Wash	24	125	19	103	18	187
Seattle, Wash	28	223	21	101	15	71
Portland-Pasco-Spokane Airway:						
Portland, Oreg	23	106	18	103	16	88
Crown Point, Oreg. (elevation 743 feet)	14	36	6	8	13	82
Cascade Locks, Oreg	14	40	3	6	7	29
Hood River, Oreg	17	41	6	11	3	13
North Dalles, Wash	12	57	3	5	5	16
Umatilla, Oreg	8	39	7	16	5	22
Pasco, Wash	8	38	3	8	3	15
Spokane, Wash	16	74	10	22	9	61
Pasco-Boise Airway:						
Pasco, Wash	8	38	3	8	3	15
La Grande, Oreg.[1]	5	9	2	6	3	5
Baker, Oreg.[1]	5	15	4	10	4	15
Weiser, Idaho.[1]	5	6	13	26	15	59
Boise, Idaho	9	23	0	0	0	0

[1] Data for intermediate stations on this airway interpolated from sequence reports.

TABLE 2.—*Reports of dense fog at 4-hourly periods with pressure at which fog occurred and percentage of cases*

Total cases reported November 1933	Sea-level pressure	Percentage of cases	Total cases reported November 1933	Sea-level pressure	Percentage of cases
	Inches			*Inches*	
6	30.00–30.09	1.2	104	30.40–30.49	20.8
53	30.10–30.19	10.6	19	30.50–30.59	3.8
125	30.20–30.29	25.1	2	30.60–30.69	0.4
189	30.30–30.39	37.9	1	30.70–30.79	.2

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WINTER FOGS IN THE GREAT VALLEY OF CALIFORNIA

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An effort is made in the following discussion to establish two facts concerning fogs in the Great Valley of California: First, that the more extensive fogs have their inception only after the first seasonal rains, and that their development at any time during the winter is dependent on a wet ground. Second, that in the initial stages of their development they appear as ground fogs, or as fogs with the lower surface resting on or within a few feet of the ground,[1] rather than in the form of stratus cloud.

This Great Valley, which comprises the Sacramento and San Joaquin valleys, is an elongated area covering 20,000 square miles, roughly, and is surrounded by mountains averaging approximately 3,000 feet in height on the westward side, and more than 5,000 at the northern and southern extremities and on the eastward side. By the configuration of the land, the valley is protected from any horizontal movement of the air, except through a few passes in the coastal range, a condition which permits atmospheric stagnation, and favors its prolongation. It is during these quiescent states that protracted spells of fog and stratus cloud occur in the winter months; fogs of such extent and persistence as to impede or prevent travel by auto, train, or airplane, and therefore of much concern to operators of public conveyances. Some concept of the extent of these fogs may be acquired from the fact that during January of 1934, there were 350 hours with fog or stratus cloud, at no time with a ceiling higher than 1,000 feet, at Fresno, and 335 hours at Sacramento, or very nearly one-half of the entire 744 hours of the month. Fogs with their inferior surface resting on the ground occurred in varying degrees of intensity on 28 days of this month at Fresno and on 23 days at Sacramento. In this connection it is well to state that the data in this paper were obtained from the charts at the San Francisco office of the Weather Bureau and from the forms of the various airport stations in the valley. These forms contain for each day an hourly record of the temperature, dew point, wind direction and velocity, horizontal visibility, and height of ceiling.

The beginnings of these long periods of stagnation in the cooler months of the year usually are associated with subsidence in the Polar Pacific[2] air-mass which overspreads the far west after the passage of a cyclone to the eastward. Fogs develop readily in the valley under these conditions, and are frequent from the latter part of November to February. If rains are general and of appreciable amounts in the valley immediately preceding these stagnant conditions, fog often engulfs the entire area for a period of from several days to the major part of a month. Through the winter months the days are only about 10 hours in length and the sun's altitude relatively low, so that warming in the daytime is not adequate to offset the loss of heat by radiation during the much longer nights from the ground and the moist stratum of air usually confined in the valley under stagnation. Fogs do not occur in this season alone; they also form in the early spring and late fall, but with considerably less frequency, and usually are of short duration. This, of course, would be expected since the nights are much shorter, and nocturnal cooling by radiation is too often insufficient to lower the temperature to the dew point through the required depth of moist air.

The first occurrence of fog in the season occasionally is in the fall months after there has been a definite trend to cooler weather and the nights have become materially longer. But, it is almost axiomatic with the district forecasters at the Weather Bureau office in San Francisco that fogs or stratus clouds of a general character do not develop until after the first seasonal rains; and that if their development does not follow within a few days of the first rainy spell it will be delayed until after a later rain. The close relation between rains and fogs in the

[1] Dense fogs of considerable thickness; the term "ground fog" applies to fog which obscures objects on the ground, but does not materially obscure the sky. Both types are to be distinguished from stratus cloud or "high fog".

[2] Referred to in this paper as such, although it usually is modified or transitional Polar Pacific air.

Great Valley is one of prime importance in understanding and forecasting the development of these fogs, and is the one of two precepts which necessarily must be established first.

For this purpose a study was made of the initial rains and fogs of each season during the 30-year period from 1904 to 1933, inclusive, at Red Bluff and Fresno, representing, respectively, the northern and southern portions of the valley; and during a 29-year interval, beginning 1 year later, at Sacramento, which is situated in the central and lower part of the valley near the confluence of the Sacramento and San Joaquin Rivers. Through all of these years there were only two cases of any fog at Fresno prior to the first rain of the season, only one case at Sacramento, and none at Red Bluff. In just 3 years out of 30, and at only 2 of the 3 stations, did fog develop before the first rain—a significant fact overlooked in the many discourses published on the causes of fog formation, and even more significant when on examination of these three instances it is found that the fogs were merely local in character and occurred for a short time only near sunrise on not more than 3 days. Unquestionably these fogs were quite shallow, and a result of cooling by radiation of a thin stratum of relatively moist air in the low lands.

It does not necessarily follow that the formation of fog begins after the first rain and before the second rainy period; in fact, the more general fogs would not develop if the stagnated air-mass were of Polar Continental origin and hence had very low specific humidity; nor would they develop if there were an early displacement of the Polar Pacific air over the valley by an air-mass of different characteristics, or if turbulence were too great, or if the temperature element were not suitable, or if the rain were too light to thoroughly wet the soil which has become parched and dry at the end of the long desiccating summer. Too, there is a certain band of temperatures above and below which the more extensive and tenacious fogs do not develop. Observers suggest that this band extends from near the freezing point to approximately 50° F., and a cursory examination of a few instances substantiates this suggestion.

In the 28 years in which no fog was observed before the first rain, there were 4 years at Fresno and 5 at Sacramento in which fog formed after the first rains, but their formation was delayed more than a week after any rain, whether it was the first seasonal rain or not. Red Bluff was not considered in this phase of the study, as it was frequently impossible to distinguish stratus cloud from cloud arising from other causes. Again, in these instances the fog was rather local, and not the more general type with which this paper is concerned. Furthermore, in all years of the record investigated the intense fog situations developed within the limited time of 7 days after the first or a subsequent rain.

We cannot escape the fact, then, that the more widespread and prolonged fogs have their inception not only after the seasonal rains have begun but within a period of a few days or a week of these rains. Of course, the foregoing discussion applies primarily to the initial fogs of the season, but innumerable cases of fogs on later dates have been examined and they were invariably preceded by rain by not more than about a week. There are no apparent physical reasons by which to refute a deduction that rain is a prerequisite of fogs in the valley at any time during the season, as well as of the initial fogs. Conditions are similar, and the factors involved are in the same relation to each other, whether it be in connection with the first fogs or those of a later date.

Without a wet valley floor, regardless of the water vapor content of the Polar Pacific air that overspreads the valley at the outset of a period of atmospheric quietude, fogs will not materialize, except possibly those of a local character. A careful study of some typical cases shows that evaporation of moisture from the wet ground into the lowest stratum of air is the final link between those instances productive of fogs and those nonproductive of fogs, all other factors being similar in each one. The amount of moisture accumulated in the lower layers of the air from the wet ground varies considerably between individual instances. Influenced by several factors, the amount existing at different points in the valley also shows a rather wide variation. Those instances examined showed an increase of from one to five grams per kilogram in the moisture content of the lower air stratum as a result of evaporation. Frequently the water vapor content of the air was increased more than twofold.

When the Polar Pacific air encroaches on the Pacific Slope, its specific humidity is rather uniformly distributed up to a height of several thousand feet. Usually the occupancy of the valley by this newer air-mass is immediately preceded by rain in the valley, in which case evaporation from the wet ground increases the water vapor content of the lowest layers of this air. Simultaneously with, and as a result of, this evaporation the heat of vaporization decreases the temperature or impedes any rise in temperature of the ground. Often a part of the mass of air associated with the cyclone is entrapped in the valley by the cooler and somewhat drier air; especially is this true of the San Joaquin Valley. This in no way alters the fog conditions; in fact, it is favorable to fog formation by increasing the water vapor content of the newer air-mass. In other instances, where the anticyclone spreads over the valley about a week or more after rain has fallen, there is no general fog development; or if the development does not begin within about a week after the rain, it is delayed until the cycle of events is repeated on a later date. The explanation is offered that during a period of approximately a week after rain, the ground has become quite dry due to evaporation—usually an almost cloudless sky follows periods of unsettled, rainy weather, unless fog develops. This evaporated moisture is diffused to considerable heights, and much of it carried away by the end of a week or more. Therefore, there can be no appreciable addition of water vapor to the low levels of an air-mass that overspreads the valley later than a week after rain. Neither can there be any concentration of water vapor in the low levels later than a week after the rain, since then the ground will have become too dry again to yield any material amount of moisture.

In those cases which lead to the development of the more general and tenacious fogs, evaporation from the wet soil results in the addition of moisture to the atmosphere, and a decrease in temperature of the ground. This process, however, is not completed in 1 day; sometimes it may extend over the greater part or all of a week, during which time the specific humidity is progressively increased and the surface temperature decreased or its rise retarded. Unmistakably the inference is that ground fogs or fogs with their surface on or near the ground make their appearance first, followed later by deeper and more persistent fogs as evaporation and cooling continues. Subsequently, as the subsidence inversion developes, stratus cloud makes its appearance.

This inference brings us to the second precept set forth above, which is justified in view of the many cases of fogs examined, all of which revealed the presence of ground fogs or fogs with their inferior surface resting on or near the ground before the appearance of stratus cloud. During the winter of 1933–34, there were three prolonged foggy periods, December 20 to 28, January 3 to 21, and January 28 to February 4 (all dates inclusive), and in each case low fogs were general throughout the valley for several days prior to the observance of stratus cloud. When an anticyclone overspreads the valley, evaporation from the wet soil begins, and the water vapor content of the lowest layers of this air is increased while the heat of vaporization lowers, or impedes any rise in, the temperature of the ground. Radiation from the ground and from this stratum of air, in which there has been a concentration of water vapor, results in fogs during the night and early morning, which in their early stages are shallow and of short duration. On succeeding days evaporation continues, but convection, even though feeble on these short winter days, and turbulence carry some of the added water vapor to increasing heights, with the result that recurrent fogs become deeper, more general, and of longer duration. Too, after the fog has developed, it and any uncondensed water vapor in or above it, continue to radiate heat, at a considerable rate, while the return radiation from the much drier air above is negligible, so that there is a marked net loss of heat by the fog. There is a net loss by it in the daytime also, though not quite so large, because nearly 80 percent of the incident solar radiation at the top of the fog is reflected while the emission from the fog is unchanged. Therefore, just as radiation of heat from the ground and moist air stratum is the cause of the formation of fogs, so is it the means by which they are maintained as well as increased in thickness. Ultimately the fogs become increasingly difficult to disperse, and when the subsidence inversion is established they continue throughout the day.

The inferior surface of the fog becomes quite variable now, and may rest several hundred feet above the ground as often as on the ground. During the daytime a portion of the remaining 20 percent of the solar radiation not reflected by the fog penetrates to the ground, and the warming that ensues, though slight indeed, is ample to dissipate the lower stratum of the fog. This thinning occurs in the nighttime as well, due to the fact that long wave radiation from the ground is absorbed readily by the fog particles which absorption tends to warm this layer, and gradually dissipate the fog near the ground; but all the while, loss of heat by radiation from the fog is proceeding rather rapidly with the result that its upper layers become denser. The fog is not necessarily dissipated altogether near the ground, but may continue in varying degrees, either day or night, with a horizontal visibility ranging from one-fifth mile to several miles. However, the air temperature and dew point rarely become separated by more than one or two degrees under this stratus cloud; therefore it follows that a slight change in temperature, or possibly in some other factor, would result in the redevelopment of dense fog. Hence, while stratus cloud, or "high fog", continues unbroken it frequently extends to the ground in varying degrees of density, and this condition persists until the air-mass involved is displaced by one of different characteristics. Some years ago E. H. Bowie, in connection with his long study of summer fogs in the California coastal region, also observed a relation between winter rains and fogs in the interior valleys. W. E. Bonnett, in charge of the Fresno office of the Weather Bureau for many years, included the following statement in an official letter some time past: "Briefly, observation and the records show that the high fogs, so-called, in the San Joaquin Valley, have their beginnings in ground fog."

The accompanying graphs and chart illustrate to some extent the conditions favorable to, and the physical activity in process during, the development of a protracted spell of fog. This period, January 24 to February 4, 1934, covers the last of these anticyclonic periods of "gloom" of the past winter 1933–34, and would be a typical instance but for the belated development of fog. On January 23 light to moderate rains fell throughout northern California, and by the afternoon of this date the

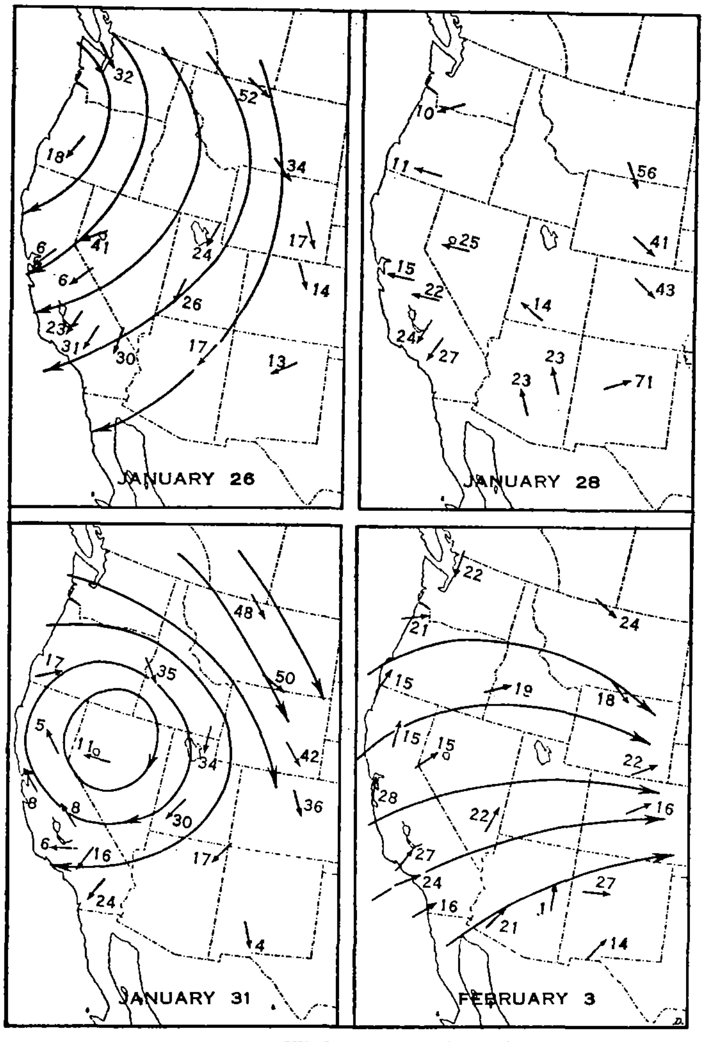

FIGURE 1.—Wind at 12,000 feet (3 p. m.).

Polar Pacific air made its appearance along the Pacific slope. Clearing skies and decreasing specific humidity began on the same afternoon, and by noon of the 24th the specific humidity at San Francisco and Williams (located in Sacramento Valley) had decreased to approximately 3 parts per 1,000, or about one-half the value on the preceding day. The average on the 24th was 3.3 g/kg at San Francisco and 3.8 g/kg at Williams.

Northerly gales prevailed aloft on the 24th and 25th, but near the surface at San Francisco the wind was light to moderate north or easterly or calm, and the center of this new air-mass was over Oregon. Under such wind conditions there could be little additional air transported directly from off the ocean; even so on the first day this is shown to possess a water vapor content of not more than 4 g/kg. However, there was a sharp increase in the water vapor content of the air in the valley from the afternoon of the 24th to the 25th (fig. 2), unquestionably the result largely of evaporation from the wet ground. The winds aloft had veered to northeast by the afternoon of the 26th (see lines of flow in fig. 1) and were either from the same direction near the surface at San Francisco or were light variable or calm. The air movement was now from the elevated plateau to the northeastward, but there was a further sharp increase in the absolute humidity in the Great Valley. The average specific humidity at Williams on the 26th was 7 g/kg, an increase of 3.2 g/kg or 46 percent over the average on the 24th. This can be accounted for in large measure only by means of the addition of moisture from the ground.

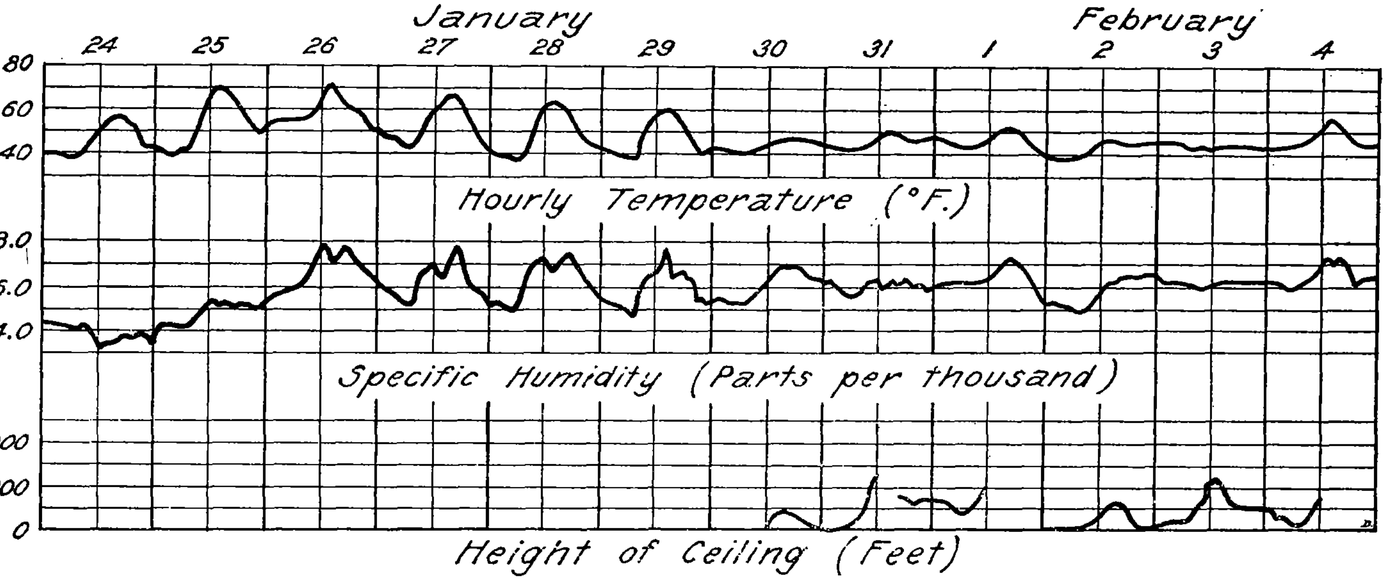

FIGURE 2.—Williams, Calif., January 24–February 4, 1934, inclusive.

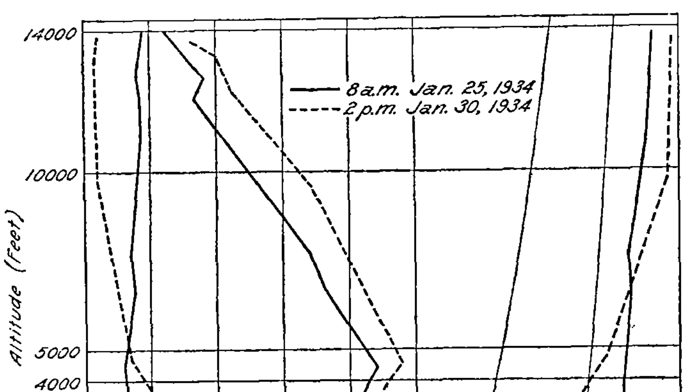

FIGURE 3.—Sunnyvale, Calif.

The center of the anticyclone had advanced to the central Great Basin by the morning of the 30th, but after the 28th there had been a steady decrease in intensity. This would indicate subsidence was in effect over the far west. An anticyclonic circulation also appeared in the upper air over the region west of the Rocky Mountains, with the center over Nevada, and light southeasterly winds prevailed over California (fig. 1). This also indicated subsidence over the Great Valley. Note the higher temperatures above 3,000 feet at Sunnyvale on January 30 (fig. 3) and the appearance of an inversion of temperature below this level. There had also been an increase in both the relative and absolute humidities below 5,000 feet, and a corresponding decrease above this level. Fog had developed during the night of the 29th–30th over much of the Great Valley; the first at Williams was just past midnight. It was a dense fog with a ceiling of zero, indicating conclusively that it was resting on the ground rather than in the form of stratus cloud. This dense fog continued until noon of the 30th, but had again extended to the ground by 10 p. m. Beginning with February 2 and continuing until the afternoon of the 4th, the sky was overcast, with the ceiling varying between zero and 1,200 feet. On the morning of the 2d the winds aloft over California had definitely shifted to the southwest with increased velocities, and it was obvious that the foggy regime would not be long-lived. During the latter part of the 4th and the morning of the 5th this new air-mass penetrated into the valley, and the last fog of the season was definitely ended.

The effects of afternoon convection are clearly depicted on the specific humidity chart (fig. 2), and it is interesting to observe the immaterial diurnal range in temperature and specific humidity during the days when fog prevailed. It is also interesting to note the well defined anticyclonic circulation in the upper air during the period just prior to and during the fog, as indicated by the lines of flow drawn on the charts in figure 1.